BEFORE THE
FEDERAL COMMUNICATIONS COMMISSION
WASHINGTON, DC 20554

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FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

In the Matter of	)	
	)	
Revision of the Commission's Rules	)	CC Docket No. 94-102
To Ensure Compatibility With	)	DA 98-2631
Enhanced 911 Emergency Calling Systems	)	

To: Chief, Wireless Telecommunications Bureau

REPLY OF U S WEST WIRELESS, L.L.C.

U S WEST Wireless, L.L.C. ("U S WEST") hereby responds to the oppositions filed against the requests for a waiver of Section 20.18(e) of the Commission's rules filed by U S WEST and other commercial mobile radio service ("CMRS") providers. *See Public Notice*, DA 98-2631 (December 24, 1998).

U S WEST and other waiver applicants have no economic interest in the success or failure of a particular solution and U S WEST remains committed to meeting the Commission's E911 Phase II requirements. In fact, U S WEST (among others) expressly confirmed that it has not determined whether it will pursue a network, handset, or hybrid solution to the Phase II requirements. The current requirements, however, are inherently biased in favor of network solutions and thus may preclude the development and deployment of promising, cost effective handset solutions. Thus, absent the requested waivers (or rule modification), U S WEST and other CMRS providers may be forced to purchase network products without regard to technical, cost, or other shortcomings simply because handset solutions cannot be fully deployed prior to October 1, 2001.

This result is at odds with the Commission's desire to ensure that the rule be "technologically and competitively neutral"and, more importantly, may severely disserve the

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public interest and consumers if handset solutions prove viable.[1] The Commission should not pick technology "winners and losers" and should not permit regulatory fiat to distort technical and competitive developments which may significantly advance the public interest.

Six parties oppose the waiver requests.[2] Almost universally, and not surprisingly, these parties are developers of *network-based* solutions to the Phase II requirements.[3] The Opponents generally maintain that, because network solutions are available *now,* waivers should not be granted to permit the phased-in implementation of "potential" handset solutions which, in their view, have technical shortcomings.[4] Contrary to the assertions of the Opponents, however, the record at this time demonstrates that no technology — whether network or handset — is currently commercially available or has proven to be a viable solution.

Instead, as discussed below, the waiver applicants have demonstrated that it is too early to determine whether handset or network solutions will be capable of satisfying the Commission's rules, but that current developments with respect to handset solutions support grant of a

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[1] *See Revision of the Commission's Rules to Ensure Compatibility with Enhanced 911 Emergency Calling Systems,* CC Docket No. 94-102, *Memorandum Opinion and Order*, 12 F.C.C.R. 22665, 22725 (1997) ("*E911 MO&O*").

[2] Cell-Loc Inc. ("Cell-Loc") Comments (Feb. 16, 1999); KSI Inc. ("KSI") Reply (Feb. 16, 1999); SigmaOne Communications Corporation ("Sigma") Opposition (Feb. 16, 1999); TruePosition, Inc. ("TruePosition") Response (Feb. 16, 1999); Texas Advisory Commission on State Emergency Communications and Texas Emergency Communications Districts ("TAC") Comments (Feb. 16, 1999); National Emergency Number Association, the Association of Public-Safety Communications Officials - International, Inc., and the National Association of State Nine One One Administrators ("NENA") Comments (Feb. 4, 1999). Hereinafter, these parties will be referred to collectively as "Opponents."

[3] Two parties without economic interests in either network or handset solutions opposed the grant of waivers, on the ground that waivers would delay implementation of Phase II ALI. *See generally* TAC Comments; NENA Comments. As discussed below and in U S WEST's waiver request, these concerns are misplaced.

[4] *See* TruePosition Response at 9; KSI Comments at 10; Cell-Loc Comments at 7.

conditional waiver or rule modification. Favorable Commission action will provide the CMRS industry with the essential flexibility to evaluate different solutions and to choose the one that proves most accurate, reliable, timely, and cost-effective. *This* is the solution that serves the public interest.

I. BOTH HANDSET *AND* NETWORK SOLUTIONS TO THE PHASE II ALI REQUIREMENTS ARE STILL IN THE DEVELOPMENT PHASE

U S WEST has acknowledged the potential shortcomings of potential handset solutions, many of which were reiterated by the Opponents.[5] Not surprisingly, however, the Opponents appear to overstate the shortcomings of handset solutions and fail to mention some of the current shortcomings associated with *network* solutions. As discussed below, network solutions *may* be incapable of providing Phase II ALI in certain areas where geometry and multipath issues pose problems. Rural areas may pose particular difficulty. Moreover, even if it becomes technically possible for network solutions to provide Phase II ALI in all environments, it may be cost prohibitive to do so.

A. The Record Does Not Establish That Network Solutions Are Currently Available for All CMRS Networks

According to the Opponents, waivers of the Phase II requirements are not warranted because network solutions capable of supplying Phase II ALI to all types of networks are currently available and GPS-enabled handsets may never be capable of supplying this

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[5] U S WEST Petition at 6. One of the Opponents asserts that the problems associated with handset solutions would disappear if manufacturers incorporated ALI technology into all handsets. *See* Cell-Loc Comments at 2. In this regard, Texas Instruments has stated that as a result of digital signal processing, "*every digital cellular phone sold [two years from now] will have a global positioning system or GPS.*" *See* "Digital Signal Processing at the Heart of Digital Connectivity," Press Release (Oct. 5, 1998) (emphasis added) (Attachment A).

information.[6] This bold statement is impressive — but apparently not true. Simply put, there is no evidence to support the claim that network solutions are commercially available at this time.

The oppositions themselves contain contradictions indicating that network solutions in fact either require additional development work or are not yet available for a number of networks. For example, TruePosition claims that its "ALI technology is capable of determining the location for all existing types of analog and digital CMRS networks (GSM, TDMA, CDMA, ESMR) well within the Phase II requirements."[7] In the very next sentence, however, TruePosition notes that it "is *initiating* field trials for its *first* CDMA system in the second quarter if this year."[8] KSI Inc. notes that it does not yet have either a CDMA or GSM compatible solution for Phase II ALI.[9]

In addition, the waiver applicants and equipment vendors also have challenged the assertions of the Opponents that network-based solution are available for all types of networks. For example, both AT&T and Tritel, Inc. note that "despite the claims of some equipment manufacturers to the contrary, there is currently no network-based solution available for carriers using Time Division Multiple Access ("TDMA") technology in their wireless networks."[10] Similarly, Ariel Communications, a GSM-based carrier, asserts that it is unaware of any "wide scale field trials" demonstrating the feasibility of a network solution for GSM systems. Thus, the

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[6] *See* note 3 *supra*.

[7] TruePosition Response at 4.

[8] TruePosition Response at 5 (emphasis added).

[9] KSI Comments at 11.

[10] AT&T Wireless Services, Inc. Comments at 2-3; Tritel, Inc. Comments at 2.

record casts doubt on the current availability of network solutions for TDMA, CDMA, and GSM networks.[11]

B. Network Solutions May Be Unable To Provide Compliant, Cost-Effective Phase II ALI

The record demonstrates that network solutions require a minimum of two or three cell sites within a specified geographic area in order to provide ALI that meets the Phase II requirements.[12] As United States Cellular Corporation ("USCC") noted:

> "Network" based Phase II solutions involving base station and switch modifications, will be dependent on having a sufficient number of cells in a given area to allow the system to determine where an E-911 caller is by the use of signal "triangulation" techniques. However, in many rural cellular systems, including some of those operated by USCC, which use relatively few, high powered, omnidirectional cells, there is not now (and may not be by 2001) sufficient cell "density" to accomplish the location of callers within 125 meters or less [using a network solution].[13]

Others similarly noted that the construction of additional cell sites would be required to create the density required for network solutions to work.[14] The construction of such sites would not only be costly, but would be dependent upon third party approvals and numerous factors beyond

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[11] U S WEST is unaware of any comprehensive field tests establishing that network solutions have solved the problems associated with rural areas. Celulares Telefonica ("CT") asserts that it is actively working with Ericsson Caribbean to *develop* a network-based solution for its system. CT Comments at 2. Presumably if a cost-effective, reliable solution were already available for CT's system, this work would be unnecessary.

[12] *See* Advantage Cellular Systems, Inc. ("Advantage") Request for Waiver at 2; Arctic Slope Telecommunications and Cellular Inc. ("Arctic Slope") Request for Waiver at 2; Chariton Valley Wireless Services ("Chariton Valley") Request for Waiver at 2; New Mexico RSA-6 III Partnership ("New Mexico") Request for Waiver at 2; South #5 RSA Limited Partnership ("South #5") Request for Waiver at 2; Texas RSA 7B3, Inc. ("Texas 7") Request for Waiver at 2. *See also* KSI Comments at 11; TruePosition Response at 8 n.18.

[13] USCC Contingent Request for Waiver at 2-3.

[14] *See* Advantage Request at 2; Arctic Slope Request at 2; Chariton Valley Request at 2; New Mexico Request at 2; Texas 7 Request at 2; USCC Request at 2-3.

the control of CMRS licensees.[15] Despite their bold statements elsewhere in their oppositions, both KSI and TruePosition acknowledge the shortcoming and note their attempts to develop the capability for network solutions to use a single cell site to provide Phase II ALI.[16] Again, these statements belie their claims that compliant network solutions are currently available.

A number of waiver applicants estimated the cost of deploying a network solution — including the deployment of new cell sites — in rural areas to be between \$350 and \$6,600 *per subscriber* depending upon the size and population of the market.[17] It also has been estimated that a network solution will cost more than twice as much as a handset solution in rural areas.[18] This problem is not simply limited to a few small carriers. U S WEST, Sprint, AirTouch, AT&T, Western Wireless and a number of other large CMRS providers provide service in many rural markets.

The cost of network solutions has been estimated to be \$10,000 to \$50,000 per cell site. In turn, it has been estimated that the total cost to the wireless industry for merely *retrofitting* cell sites will be \$6.25 billion.[19] This cost could increase substantially if additional cell sites are

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[15] In addition to problems in rural areas, network solutions also suffer from "interference and signal reflection (multipath)" problems. *See Revision of the Commission's Rules to Ensure Compatibility with Enhanced 911 Emergency Calling Systems,* CC Docket No. 94-102, *Notice of Proposed Rulemaking*, 9 F.C.C.R. 6170, ¶46 (1994).

[16] KSI Comments at 11; TruePosition Response at 8 n.18.

[17] *See* Advantage Request at 2 (\$1,160 per subscriber); New Mexico Request at 2 (\$635 per subscriber); South #5 Request at 2 (\$350 per subscriber); Texas 7 Request at 2 (\$6,600 per subscriber).

[18] Advantage Request at 2.

[19] PCIA Ex Parte, Phase II Implementation Cost (March 24, 1997).

needed to create the "geometry" necessary for network solutions.[20] In sum, it may be cost prohibitive to use network solutions. The cost issue is real — one which should not be ignored by Opponents or the Commission.

C. Although Handset Solutions Still are in the Development Stage, Many of the Criticisms Leveled Against These Solutions Appear Unfounded

The Opponents level numerous criticisms against handset solutions, but it appears that many of these criticisms are unfounded.[21] For example, the Opponents claim that handset solutions require "line-of-sight" availability and thus cannot work inside buildings or in urban canyons.[22] The preliminary test results cited by U S WEST in its waiver request, however, contradict these claims.[23] These results indicate that callers can be routinely located within 22 meters "within two story buildings, both wood and brick," and within 45 meters in urban canyons.[24] Similarly, although TruePosition cites to a Motorola submission for the proposition that tests of handsets using an internal GPS antenna will lead to significant performance degradation,[25] the validity of this submission was challenged some time ago.[26] Again, the Commission should not dismiss the promising, albeit preliminary, indications that handset

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[20] *See* USCC Request at 2-3.

[21] The Opponents also criticize the numerous field test results submitted by U S WEST and others, but they fail to submit any test data substantiating the accuracy and reliability of their network solutions. Moreover, test results indicate that handset solutions provide the potential for three dimensional location information not available via network solutions. *See* Sprint Spectrum, L.P. ("Sprint") Waiver Request at 2 (Feb. 4, 1999).

[22] *See* TruePosition Response at 13; Cell-Loc Comments at 4-6.

[23] U S WEST Petition for Waiver at 5-7 (Feb. 4, 1999).

[24] U S WEST Petition at 6.

[25] TruePosition Response at 12 n.28.

[26] *See* "SnapTrack Enhanced GPS Technology: Field Test Results Using Prototype GPS Handset Antenna, Including the Impact of User Head Blockage" (Attachment B).

solutions may prove to provide cost effective and viable solutions to the Phase II ALI requirements.

II. GRANT OF U S WEST'S WAIVER REQUEST IS SUPPORTED BY THE RECORD AND IS CONSISTENT WITH THE PUBLIC INTEREST

The Opponents claim that grant of the waivers will undermine the Commission's stated policy of technological and competitive neutrality.[27] Rather than let the marketplace determine the best available solutions, the Opponents contend that waivers will promote handset solutions at the expense of network solutions.[28] This simply is incorrect.

The Commission has expressly acknowledged the possibility that waivers of the Phase II deadline may be warranted to facilitate "the development and deployment of the best and most efficient ALI technologies and systems."[29] Consistent with the instant waiver requests, the Commission also acknowledged that it "would consider proposals to phase in implementation, especially to the extent a proposal also helps achieve the further improvements in ALI capabilities."[30]

U S WEST's waiver request is fully consistent with these pronouncements. First, it is expressly contingent upon the availability of a handset-based solution *prior to the October 1, 2001 deadline that exceeds the accuracy standard of the Commission's rules*. Second, it demonstrates that handset solutions *may* provide the following benefits:

- low cost solution to the provision of Phase II ALI in rural areas;
- ALI with better accuracy and reliability than required by the Commission; and

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[27] TruePosition Response at ii; Sigma Comments at 7-8.

[28] *See, e.g.*, TruePosition Response at 6.

[29] *E911 MO&O*, 11 F.C.C.R. at 22725.

[30] *E911 MO&O*, 11 F.C.C.R. at 22725.

- Phase II ALI implementation well in advance of the current deadline.

U S WEST questions the Opponents' claims that a waiver unfairly favors handset solutions. If network solutions prove to be the best, most cost-efficient systems, CMRS carriers will choose to deploy them. In reality, the Opponents appear to fear competitive forces.

Finally, to confirm, U S WEST's waiver request was not "open-ended," as suggested by Opponents If a network solution proves to be the optimal solution for U S WEST, it will be deployed in compliance with the Phase II deadline. If a handset solution instead proves optimal, handsets will be deployed in U S WEST markets prior to the current Phase II deadline. In turn, it is anticipated that ALI capable handsets will be rapidly deployed and that implementation of this solution can be achieved quickly by marketplace forces. Accordingly, grant of waivers will not unduly delay the introduction of Phase II ALI as Opponents would have the Commission believe.

CONCLUSION

For the reasons stated above and in U S WEST's Petition, the Commission should grant a waiver (or rule modification) that would deem CMRS licensees in compliance with the Phase II implementation deadline if ALI-capable handsets which exceed Phase II requirements are offered for sale prior to October 1, 2001.

Respectfully submitted,
U S WEST WIRELESS, L.L.C

By: Jeffry Brueggeman
Jeffry Brueggeman
1020 19th Street, NW, Suite 700
Washington, DC 20036
(303) 672-2799

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Digital Signal Processing at the Heart of Digital Connectivity: TI's DSP is Changing the Face of Electronics

NEW YORK (October 5, 1998) - Digital signal processing is the technology that will enable the future of communications and change the dynamics of the semiconductor industry, according to Tom Engibous, chairman, president and chief executive officer of Texas Instruments (NYSE: TXN).

"In the future, it won't matter what type of network -- wireless, landline or satellite -- or what type of pipe -- copper, fiber, coaxial or thin air. At every connection and at both ends of the network, there will be a digital signal processor," he said.

Speaking here at *The Wall Street Journal* Technology Summit, Mr. Engibous said the industry today is being driven by the surge in digital connectivity that can be seen primarily in the wireless and networking areas.

Most of today's wireless phones and systems are generally limited to one type of network, providing limited bandwidth. In the coming years, it is expected that wireless users will be putting new demands on their service providers. "Imagine this," Mr. Engibous said. "In two years, every digital cellular phone sold will have a global positioning system or GPS. Through cellular phones, police will be able to know exactly from where an emergency call is coming.

The digital cellular phone will also be able to help people navigate through unfamiliar towns, automatically finding the best routes with the least traffic, and it will be able to tell people the nearest hospital, gas station, or which Italian restaurant is nearby and what the daily specials are. All this can be broadcast on wireless networks using the GPS system that will soon be on your digital phone."

While this type of GPS is more advanced than devices offered today by some carmakers, Mr. Engibous said it can be achieved by linking the GPS task with the cellular task on the same processor. "This is where DSP fits in. By crunching numbers at incredible speeds, up to two billion operations a second, DSPs are the perfect processor for electronics that need to function in the real world where waiting is not an option.

"DSPs allow all electronic equipment to be connected, speaking the same language. By linking the cellular with the GPS, the cost is minimized, any cellular system can host the service and you can take the cellular phone with you wherever you travel."

Networking is the second force in digital connectivity. Applications like file-sharing, groupware and e-mail make it possible for better and more effective collaboration. "As a supplier to this industry, it's critical for TI to understand the issues network builders face. Many times the barriers that slow growth are not technical, they are economic," Mr. Engibous said. He cited the development of DSL or digital subscriber line technology which turns ordinary copper phone lines into high-speed data networks, carrying data at a rate more than 100 times faster than today's fastest analog modem. These lines can also be used for voice traffic.

DSP addresses a key concern for network builders -- how to keep their technology up to date. "The tremendous flexibility of DSP lessens this concern. Programmable DSPs can change the software code in the chip after they leave the factory. This means that new upgrades can be made without additional reinvestment in new hardware and changes can be made over any network from remote locations."

Another DSP solution involves a chipset that eliminates the need for telephone companies to visit a customer's premise and install a splitter on the phone line to separate voice and data traffic. This can be done through a central office, eliminating costly charges to both customers and phone companies.

"We are working closely with other communications and technology companies to agree on standards for digital subscriber lines or digital modems. It's in everyone's interest to put a set of standards in place as quickly as possible. By this time next year, the market for digital modems will start to take off and by 2001, the market is expected to reach 18 million digital modems. That kind of explosive growth will only happen if all the players share a common vision of what the network can become," Mr. Engibous concluded.

Title

SnapTrack Enhanced GPS Technology: Field Test Results Using Prototype GPS Handset Antenna, Including the Impact of User Head Blockage.

Source

SnapTrack Inc.

Authors

Dr Norm Krasner
Vice President and Chief Technical Officer
SnapTrack Inc.
4040 Moorpark Suite 250
San Jose, Ca 95117
nkrasner@snaptrackinc.com

Dr Tom Wolf
Lead Hardware Development Engineer
SnapTrack Inc.
4040 Moorpark Suite 250
San Jose, Ca 95117
twolf@snaptrackinc.com

Walter Bell
Vice President, Engineering
SnapTrack Inc.
4040 Moorpark Suite 250
San Jose, Ca 95117
wbell@snaptrackinc.com

Bruce Wilson
Manager of Technology Validation
SnapTrack Inc.
4040 Moorpark Suite 250
San Jose, Ca 95117
bwilson@snaptrackinc.com

Abstract

This contribution discusses the complexity of making accurate assessments of the issues pertaining to integrating a GPS antenna into cellular handsets. While the simplifying assumptions and direct antenna laboratory measurements made in a previous paper [1] provide a useful starting point for assessing antenna issues, the conclusions drawn in that paper from these measurements are overly pessimistic. More sophisticated antenna design considerations and advanced GPS processing algorithms can overcome much of the losses identified by direct measurements using conventional GPS antennas in handset applications. This assertion is substantiated by actual GPS location data collected using a handset mock-up, held against the head, in several difficult GPS propagation environments.

1. Background

This contribution identifies some of the issues that distinguish a laboratory experiment from the "real-world" environment and discusses how these differences can influence GPS performance. Preliminary results of actual location finding experiments, utilizing a novel handset sized GPS antenna and a state-of-the-art GPS receiver in a handset sized box in proximity to a real human head, are presented to reinforce these differences.

Integrating GPS reception into cellular handsets for the purpose of location is an area of significant controversy. Several GPS manufacturers have successfully addressed many of the issues pertaining to GPS performance in blocked or severe multipath environments with improvements in receiver sensitivity and sophisticated new processing algorithms. However these improvements need to be coupled with an excellent antenna implementation for maximum location system performance.

A handset mounted GPS antenna design faces multiple constraints not encountered in more conventional GPS applications. These constraints include extremely small size, successful operation in a variety of orientations, and successful operation in proximity to human bodies, conductive phone components, and other metallic objects such as automobile roofs.

Experiments detailed in a previous submission [1] have been performed where conventional GPS antennas were adapted to handset geometries, and the direct radiation patterns were measured when the antennas were in proximity to the human body. The conclusions drawn in that submission paint a pessimistic picture of the feasibility of GPS in handsets. However, these conclusions are not consistent with the results of ongoing live satellite experiments being conducted by SnapTrack, Inc. This inconsistency is due to limitations of the laboratory model used the previous submission [1] in predicting real-world performance. Preliminary results from these ongoing field tests are included in this contribution.

2. Limitations of Laboratory Measurement Model for Prediction of Real-world Performance

The previously presented paper [1] provided a number of antenna measurements performed in an anechoic chamber which provide very useful information on the effects of body blockage upon antennas employed by cellphones. Conclusions were then drawn based on these laboratory measurements as to the predicted field performance in a GPS mobile location application. While the laboratory measurement method is quite important in developing antenna designs, it does not accurately predict the real world performance in complex multiple (GPS) signal multipath environments in which locations are to be performed. As will be seen, the performance of the SnapTrack location technology is substantially better than that predicted on the basis of anechoic chamber measurements.

2.1 Effect of Body Blockage on GPS Coverage

The data analysis approach used by the authors of the previous paper [1] consisted of averaging the antenna response over the entire hemisphere, including those portions of the hemisphere blocked by the human body. This averaged number was then used as representative of the specific antenna performance in a GPS application. While average upper hemisphere radiation efficiency is a good metric of antenna performance in some applications, including omnidirectional transmitters, it is not an ideal metric for antennas used in GPS reception. The average efficiency provides a measure of how well, on average, a signal to anywhere will be transmitted or received. For a GPS receiver a better measure would be what is the probability that enough of the upper hemisphere has little attenuation, so that three satellites can be found. Thus, the RHCP Cumulative Distribution Function [1] is a more useful metric. However, to utilize this measure accurately, it must be recognized that the requirement is not that 87.5% of the sky be visible (which would be true if it were necessary to find all satellites above the horizon), but instead that enough of the sky be visible to find any 3 satellites. Although detailed calculations based upon orbital parameters can be performed, a rough estimate can be obtained by recognizing that at least 6 satellites are usually above the horizon, and distributed widely throughout the sky. Thus, to find three satellites, approximately ½ or 50% of the sky must be visible with acceptable attenuation. Note that the high sensitivity of the SnapTrack GPS receiver extents the sky coverage range of any antenna due to it's ability to work with substantially attenuated satellite signals. Utilizing Fig. 8 of [1], at least for the Patch antenna at the phantom's ear, the RHCP gain will exceed –4 dBiC, not the –14 dBiC cited. This loss level is well within the capability of the SnapTrack GPS receiver to overcome. This hypothesis is born out by the field test results discussed later in this paper.

2.2 Effect of Snapshot Signal Acquisition Methodology on Body Blockage

Unlike conventional GPS receivers which need to continuously monitor satellite signals over a sustained period of time, the SnapTrack GPS receiver can determine location based upon a "snapshot" of data collected over a brief period, typically 1 sec. For this receiver, body or head blockage becomes much less significant since the data can be collected while the user is dialing, when the cellular phone is held out in front of the user. This dialing position has much less body blockage than the talking position and thus greater sky visibility. In general, one would expect to perform location determinations only while either holding the phone out, or while conversing on it. Thus, GPS performance while clipped to the belt [1] is probably not a significant consideration.

2.3 Effect of Ground Bounce and Other Reflected Signals on GPS Performance

Advanced GPS receivers, including those available from SnapTrack, have not only high sensitivity, but also sophisticated algorithms for utilizing signals reflected from the ground, as well as other indirect and multipath signals, with modest degradation in accuracy. Thus, an analysis of GPS reception that is limited to direct signals in the upper hemisphere provides an overly pessimistic assessment of the ability of a GPS receiver to determine locations in a difficult environment. As specified in the test procedure, the test approach of the previous contribution [1] used an anechoic test chamber that eliminated the effect of ground bounce and other reflected signals. In comprehensive, audited field testing programs, SnapTrack has confirmed that such reflected signals, combined with a very high sensitivity receiver, are usable and in some cases may be the only available signals for location determination. Such reflected signals are particularly common to indoor and inside car environments. Since these two environments are high probability usage locations for 911 and other location based applications, we believe that elimination of reflected signals through the use of an anechoic chamber [1] substantially limits the accuracy of these lab measurements in predicting real-world GPS performance in many important harsh reception conditions. In contrast, the SnapTrack antenna testing results, presented in this paper, provide measured field performance in typical mobile location environments. Of course, substantial additional testing is required for different antenna configurations and different field environments, but these initial results clearly indicate the viability of using reflected signals.

2.4 Effect of Optimized GPS Handset Antenna Designs

An antenna that provides adequate performance and is of a suitable shape to include in a cellular phone with minimal impact is a major challenge to antenna designers. While developing such an antenna may require a substantial engineering effort, the GPS antenna alternatives used in the prior study [1] do not adequately represent the range of performance that could be achieved with more optimized antenna designs. Selecting conventional GPS antennas and adapting them to a phone seriously degrades the antenna performance. A patch antenna with a reduced ground plane performs much worse than a patch antenna with a large ground plane [2]. The location of an end fed helix relative to other metallic objects in the phone has dramatic effects on the antenna performance [2]. Optimal performance of a GPS system in a handset can only be obtained with a well designed antenna that is an integral part of the handset design. Issues such as balanced vs. unbalanced feed, use of suitable dielectrics, and proximity of ground planes and other metallic objects within the handset must be considered as part of the antenna design process. In contrast to the antennas used in the prior paper [1], the miniaturized helical antenna used for the field testing discussed in this paper has the potential for high performance in a small mechanical package more adaptable for integration into a handset. Additionally, there exists the potential for GPS antenna solutions that could be incorporated into a cell band or PCS band antenna. This combination could be another alternative to provide the needed GPS performance with a minimal impact on the handset package.

3. Relationship of Antenna Issues Between GPS and Alternate Location Approaches

Location determination using GPS is based upon performing triangulation calculations on signals received from at least 3 satellites, out of the typically 6 or more satellites above the horizon. Thus, if one satellite is blocked by the user's body, another satellite may be visible in a different direction. Location determination based upon signals received from multiple cellular base stations faces similar issues. However, it would be rare that 6 base stations would be within range from which to select 3, and all cellular signals will be approximately horizontal (where blockage is worst for these terrestrial based systems). In addition, the portion of the sky directly overhead (the "up" direction) is very useable for GPS based systems and would typically have less body blockage than the horizontal plane. Thus, the issues of head and body blockage of handset antenna coverage are even more important for location alternatives which depend on the ability of a handset signal to be picked up by multiple base stations, or for a handset to receive emissions from several basestations. Therefore, SnapTrack believes that the issues related to operation in the presence of body blockage and poor orientation are common to any method of location and that substantial antenna design work is required to ensure highly reliable operation for location services no matter the method utilized. However, the ability of GPS based solutions to make use of overhead sky visibility and the use of a snapshot based signal acquisition method, which allows sampling during dialing, give the SnapTrack system some significant advantages over terrestrial based location solutions in dealing with body blockage conditions.

4. Test Methodology

4.1 Introduction

The tests described herein are part on an ongoing evaluation program of prototype GPS antennas targeted as potential solutions for handset integration. The result presented are the initial findings and will be substantially augmented with addition testing once the next pass prototype helix antenna is received min several weeks. However even these preliminary results clearly confirm SnapTrack's assertion that the predictions of field performance made in a previous submission [1] are overly pessimistic relative to the real-world results SnapTrack has obtained.

SnapTrack has previously conducted extensive field testing of its GPS technology in a large variety of difficult environments, such as urban canyons, inside large structures and inside automobiles, using standard GPS antennas as a reference point. In some cases, the effect of head blockage was included. These field testing programs were defined and audited by wireless carriers or manufacturers, and were conducted in the San Francisco area, Denver, Tokyo and Kyoto.

Given the existing field test data described above, SnapTrack's handset GPS antenna testing program will focus on comparing results with handset antennas and head blockage with those results already achieved with standard GPS antennas. These real-world results will be combined with laboratory measurements to provide a complete picture of antenna performance.

4.2 Test Set-up and Procedure

All tests were done with a SnapTrack GPS receiver using a prototype miniaturized (10mm x 20mm) helix (see Figure 1). The GPS receiver is packaged in a metalized box roughly the size of a handset. Tests were done in three environments typical of wireless handset usage. These environments were as follows:

1. Inside a two story office complex in a windowless room (Figures 2, 3 and 4)
2. Inside a car in a parking lot with partial tree blockage (Figures 5 and 6)
3. Outdoors in a parking lot surrounded by two story buildings with partial tree blockage (Figure 7)

The first two environments contain no direct GPS signal paths. GPS location determinations done at these two sites typically use a combination of reflected and attenuated satellite signals. The third environment contains direct signal paths, ground bounce reflected signals and foliage attenuated signals.

In each test site two experiments were run:

- Thirty location attempts were made with the SnapTrack GPS receiver held away from the body in a "dialing" position
- Thirty location attempts were made with the SnapTrack GPS receiver held against the head in a "talking" position (see Figures 4, 6 and 7)

Test results are presented in Charts 1 through 6. The information is organized as follows:

- For each 30 sample test a scatter plot is generated showing the horizontal location error in meters of each location attempt. Ground truth is shown at the 0,0 point in the center of the graph.
- The number of location attempts for this set of data (always 30) is shown in the inserted table
- The percent of successful locates for the 30 attempts. Note that the SnapTrack receiver was able to achieve 100% success rates for all three sites including the tests done with head blockage.

5. Test Results

5.1 Inside Building Tests (Charts 1 and 2)

All 30 of the location attempts for both no head blockage and head blockage cases yielded successful location determinations. Accuracy was in the in the sub 25 meter range for the no head blockage case and in the sub 30 meter range for the head blockage case. As expected, the scatter diagram for the no head blockage case (Chart 1) shows a tighter error cluster (and therefore better accuracy) than the head blockage case (Chart 2).

5.2 Inside Car Tests (Charts 3 and 4)

All 30 of the location attempts for both no head blockage and head blockage cases yielded successful location determinations. Accuracy was in the sub 25 meter range for the no head blockage case and in the sub 30 meter range for the head blockage case. The scatter diagram for the no head blockage case (Chart 3) again shows a tighter error cluster than the head blockage case (Chart 4).

5.3 Outside, Under Tree Tests (Charts 5 and 6)

All 30 of the location attempts for both no head blockage and head blockage cases yielded successful location determinations. Accuracy was in the sub 15 meter range for both cases. In these tests, the scatter diagrams for the no head blockage case (Chart 5) and the head blockage case (Chart 6) show similar error clusters. This similarity indicates a substantial ground bounce effect coupled with a sizeable number of direct satellite paths for both blockage cases. These conditions reduce the effect of the head blockage to the point that the location accuracy is similar for both cases.

5.4 Test Results Summary

The combination of the miniaturized helix antenna and the SnapTrack GPS receiver produced 100% successful location yields for all three test sites even under head blockage conditions. For the Inside Building and Inside Car test, head blockage reduced the resultant location accuracy by 20% (from sub 25 meters to sub 30 meters). However, even the head blockage cases yielded accuracy a factor of four better than the FCC mandate of 125 meters. For the Outside, Under Tree tests, head blockage had minimal effect of the resultant accuracy (sub 15 meters for both blockage cases) due to the presence of ground bounce signals and sufficient direct satellite paths. These results, while not yet exhaustive, clearly confirm the viability of a handset based GPS solution when an appropriate antenna design is coupled with a high sensitivity GPS receiver.

6. Conclusions

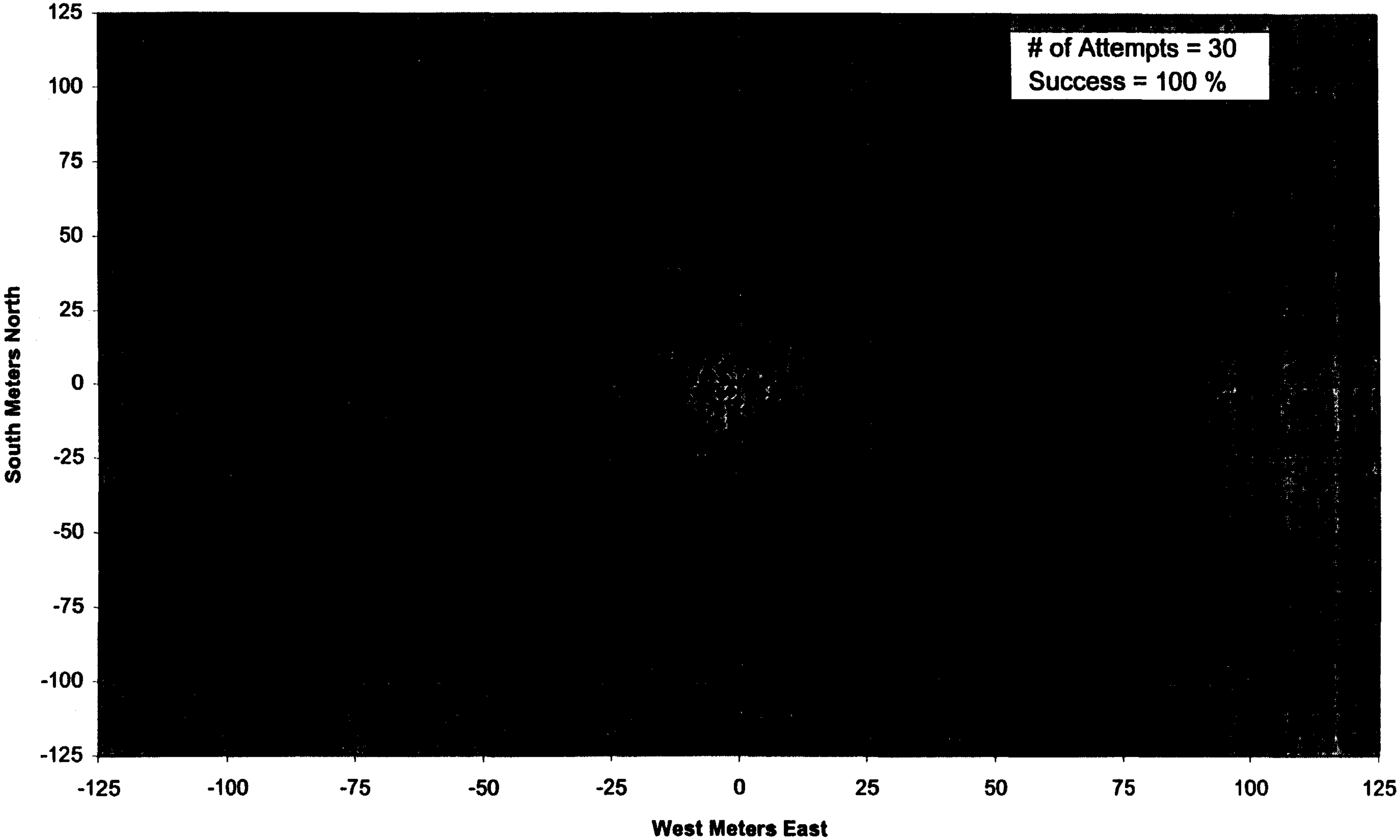
Design of GPS antennas for cellular handsets is a challenging issue. In a previous submission [1] basic laboratory experiments were performed by adapting free space GPS antennas to a handset geometry. The conclusions drawn from these measurements [1] gave excessively pessimistic predictions of the field performance of handset based GPS systems. This performance can be significantly improved by utilizing more creative antennas that were designed while considering the handset geometry. Body blockage measurements were cited [1] as additional factor in poor expectations of antenna performance, especially when considering average performance over the hemisphere and only direct path signals. In reality, a sophisticated GPS receiver needs to find only 3 satellites somewhere in the sky, and can utilize indirect signals as well as direct signals. These claims are substantiated by real world data collected with suitable antennas coupled with a high performance GPS receiver held close to human heads, in difficult environments such as indoors, or inside of vehicles.

References:

1. Krenz, E., Efanov, A, and Birchler, M., *GPS Antenna Handset Integration Issues for Assisted GPS Positioning Method*, submitted to T1P1, 7/22/1998.

2. Fujimoto, K., and James, J., Mobile Antenna Systems Handbook, Artech House, 1994.

Chart 1: Inside Building - No Head Blockage



CERTIFICATE OF SERVICE

I, Brooke Wilding, hereby certify that I have on this 22nd day of February, 1999 caused a copy of the foregoing to be served by first class U.S. mail, postage prepaid, to the following:

Thomas Sugrue, Chief*
Wireless Telecommunications Bureau
Federal Communications Commission
2025 M Street, N.W., Room 5002
Washington, D.C. 20554

James D. Schlichting, Deputy Chief*
Wireless Telecommunications Bureau
Federal Communications Commission
2025 M Street, N.W., Room 5002
Washington, D.C. 20554

John Cimko, Chief*
Policy Division
Wireless Telecommunications Bureau
Federal Communications Commission
2025 M Street, N.W., Room 7002
Washington, D.C. 20554

Nancy Boocker*
Policy Division
Wireless Telecommunications Bureau
Federal Communications Commission
2025 M Street, N.W., Room 7002
Washington, D.C. 20554

Won Kim*
Policy Division
Wireless Telecommunications Bureau
Federal Communications Commission
2025 M Street, N.W., Room 7112-B
Washington, D.C. 20554

Dan Grosh*
Policy Division
Wireless Telecommunications Bureau
Federal Communications Commission
2025 M Street, N.W., Room 7130-A
Washington, D.C. 20554

Rupaco T. Gonzalez, Jr.
Richard A. Muscat
The Gonzalez Law Firm, P.C.
One Westlake Plaze, Suite 100
1705 South Capital of Texas Highway
Austin, TX 78746

James R. Hobson
Donelan, Cleary, Wood & Maser, P.C.
Suite 750
1100 New York Avenue, N.W.
Washington, D.C. 20005

Robert M. Gurss
Wilkes Artis Hedrick & Lane, Chartered
1666 K Street, N.W., Suite 1100
Washington, D.C. 20006

Scott G. Bruce
Michael Amarosa
TRUEPOSITION, INC.
3 Bala Plaza East, Suite 502
Bala Cynwyd, PA 19004

Robert B. Kelly
Kelly A. Quinn
Squire, Sanders & Dempsey L.L.P.
1201 Pennsylvania Avenue, N.W.
Washington, D.C. 20004

Dennis Kahan
SigmaOne Communications Corporation
21900 Burbank Boulevard, Suite 114
Woodland Hills, CA 91367

ITS*
1231 - 20th Street
Washington, D.C. 20036

Brooke Wilding

*By Hand